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On recent American Determinations of Geographical Positions in the West Indies and Central America.

By Major H. S. Palmer, R.E.

A few nights ago, I paid a visit to the temporary Observatory of Lieutenant-Commander F. M. Green, of the United States Navy, erected at Rickett's Battery in this place (Barbados, West Indies). The astronomical work in which Commander Green is engaged under the American Hydrographic Office is of so highly useful and practical a character that I think a short notice of it is likely to interest the Society, or at least those of its Fellows who are practical field astronomers. It is the determination, with an accuracy much greater than any yet attained, of the geographical positions of various points in the West Indies and Central America, which are connected with one another by telegraphic cable. The latitudes in these operations are found by the method very generally used by American astronomers, of observing pairs of stars on the meridian, N. and S., with the zenith-telescope; and the longitudes, by means of telegraphic comparisons of local times. The work was begun in the winter of 1874-5, at the suggestion, I believe, of Commander Green; the U.S.S. *Fortune* was commissioned for the purpose, and Commander Green, with a sufficient staff, was placed in charge of her. During the first season, the latitudes and relative longitudes of Panama, Aspinwall, Kingston, Havana, and Santiago de Cuba were ascertained with great precision. It was intended to connect Havana at once with a station of the U.S. Coast Survey at Key West, but this was prevented by an outbreak of yellow fever. The connection has, however, been made in the winter just ended, and the work generally of this second season has been prosecuted with vigour by Commander Green and his officers, in a fresh ship, the *Gettysburg*, the *Fortune* having proved unfit for the service. Besides connecting Havana with Key West, they have determined latitudes and meridian distances at St. Thomas, Antigua, Trinidad, and Barbados, and are now at work at Martinique, where the season's operations end. In the second series of measurements, the intention at first was to establish a fixed station at St. Thomas, and measure back to it from the other islands; but this plan could not be adhered to, owing to the condition of the cables. St. Thomas having first been connected with Kingston (determined in the previous season), distances were first measured from St. Thomas to Antigua and Trinidad, then from Trinidad to Barbados and Martinique.

It is confidently anticipated that the results of the two seasons' work will prove such as to justify an extension of the measurements next year to the mainland of South America, and along both coasts, so as to settle indisputably the much-vexed question of longitudes on that continent. So far as the work has yet gone, its usefulness has been proved by the detection of considerable errors in previously received positions. It has also proved highly

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accurate and comparatively inexpensive. It is indeed plain that, when once the outfit, by no means a costly one, has been supplied and the staff trained, there the special expense of work of this kind practically ends. Any cruiser or surveying ship can carry on the measurements without prejudice to its routine services; and experience thus far has shown in the most gratifying manner that both foreign authorities and officials of telegraph companies are always ready to extend courtesy and gratuitous help to scientific work of the kind.

I proceed now to sketch the *modus operandi*, illustrating it by taking two stations, say Barbados and Trinidad, at both of which places observatory sites have been chosen by Commander Green, he himself on this occasion operating at Barbados, while his assistant, Professor Rock, is at Trinidad. The huts and instrumental outfits at both stations are exactly alike, with one exception only—the huts are of different colours. The instrumental outfit at each consists of a transit instrument adapted for use also as a zenith-telescope, a break-circuit sidereal chronometer, a small chronograph driven by a weight, keys for speaking and signalling, a Thomson's "mirror galvanometer," batteries, telegraphic fittings, lamps, &c. The transit pier is of brick, faced with cement, and is square in shape, its top surface consisting of four tiles, each about a foot square, laid and levelled with extreme care. The meridian line is laid out with a compass in the usual way. The instrument is of the large portable kind, and has a universal movement, with a horizontal circle of about ten inches diameter, a form of construction which admits of its being very readily used, if required, for observations in the prime vertical. Its base consists of a tripod-stand, with footscrews, carrying a cylinder which receives the vertical axis, and to which the horizontal circle is fixed. From the head of this axis, two opposite arms extend horizontally, and are then bent up to form the supports for the telescope axis, which are about eighteen inches apart. The telescope is of the axis-view construction, and its object-glass is of about $2\frac{3}{4}$ inches clear aperture, and 27 inches focal length. The finding-circle is on the eye-end of the axis. The transit threads are eleven in number, viz.: a central group of five, with a group of three a little on either side of it, all of them being fixed. There are the usual central horizontal threads, and others arranged obliquely for zenith-telescope work; there is also a movable zenith distance micrometer wire.

This instrument, like most of its class, is subject to one rather serious source of error, through flexure of its transverse axis, the error produced varying, just as a level error, with the cosine of the zenith distance of the body observed. The extent of this defect was however carefully investigated in the United States before the expedition set out, and a coefficient of flexure was found for each instrument, from scrupulously careful observations at every 5° of zenith distance.

The hut, about 9 feet square, has its door in the middle of the

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north side. On a table in the north-east corner is the break-circuit chronometer, in connection with a small barrel chronograph driven by a weight and wheel-work, which stands on a little table in the north-west corner. The performance of this chronograph is very satisfactory. A pencil attached to the electro-magnet describes an endless spiral on the chronograph sheet, making however a little nick or notch whenever it is momentarily moved aside by the action of the electro-magnet, either through the operation of the chronometer at each second or from the observer's tap with his break-circuit key. The numeration of seconds is marked in the usual way, by omitting the record of one second in each minute. On the same table with the chronometer is the speaking instrument,* connected with the head telegraph office, and used also in the time-signalling; and above it is the Thomson's galvanometer, its mirror reflecting a small rectangular patch of light from an orifice in a screened lamp on to a sheet of white paper fastened to the wall of the hut above the table. The break-circuit key used in tapping transits, &c., for chronographic register, with its attached wires, is movable. During transit observations, it can be held in the hand, or laid on the pier: Commander Green preferred the former.

I was with Commander Green on his first night's work at this place. There was nothing new in his method of adjusting the instrument to the meridian. It was done, however, with most unusual speed, partly owing, no doubt, to an admirable printed form of "Programme," in which the observer enters beforehand the name, position, magnitude, setting, &c. of every star he intends to use, and is thus able to proceed from star to star with the least possible loss of time. Twelve minutes' work enabled Commander Green to get his instrument very approximately into position.

For the time determination, clock stars of north declination, and therefore near the zenith, of this place, were chiefly used. The level (a most excellent one) was on this account read very frequently; but, as the construction of the instrument allows of the level being kept on the pivots without being disturbed except for reversal, this gave little trouble. Some clock stars a little N. of the zenith, and some S. of it, were observed. The usual routine is to observe 3 or 4 circumpolar, and 8 or 10 clock stars nightly, about half of each before and after time-signals, and half in each position of the axis, reversal being made on a circumpolar star once in the evening. A test value of the collimation error of the middle wire is obtained from this reversal; but in the reduction, both the collimation and azimuth errors are treated as unknown in the series of equations for clock error, and are rigorously solved for by the method of least squares.

In time-signalling, the process is as follows:—Let B and T be the operators at Barbados and Trinidad respectively. About

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* This is a double "Key" for sending positive and negative signals.

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sunset, weather prospects are telegraphed between the two, and these being satisfactory, arrangements are made for signalling at about 9^h or 10^h. At the appointed time, B calls T, and finding him ready, seats himself at the chronometer, and sends the following signals:—

A warning rattle, beginning at 50 secs., and lasting for 5 secs.

Single signals, at 0^s 5^s 10^s 15^s 20^s . . . . and so on to 60 secs.

A rattle at 5 secs., lasting for 5 secs.

T, having darkened his hut sufficiently, just acknowledges the warning rattle: then, taking the movable break-circuit key, which is in circuit with the chronograph, into his hand, he watches for the first movement of the patch of light which is reflected on the white paper from the Thomson's galvanometer. Each five-seconds signal sent by B is recorded on the chronograph when received by T, who strikes his key every time directly the light-spot is seen to move. The single signals over, T acknowledges B's last rattle.

B now promptly telegraphs the hour and minute of his first single signal, and T acknowledges it.

At the next 50 secs., B begins again with a rattle, and exactly repeats with T the above operation; and this is done five times in all.

Then T takes the sender's, and B the receiver's place, in precisely the same manner, for five minutes. This ends the night's signalling.

Three such nights of comparisons are considered to be sufficient for a pair of stations.

The time occupied by the passage of signals from the sending-point through the cable (up to the instant of visible movement of the light-spot), and also through the chronograph circuit at the receiving station, may be considered as eliminated by sending the signals both ways. But, as the observers do not change places at any pair of stations, there will remain as constant sources of error, affecting measurements of meridian distances by this method, the personal equations of the observers, (1) in observing transits; (2) in tapping the key at the sending station in coincidence with the chronometer beats; (3) in tapping the key at the receiving station simultaneously with the first visible movement of the beam of light. These sources of error have been carefully gone into amongst the observers engaged in the work.

For determining the absolute personal equations in observing transits, a "personal-equation machine" was used. Two or three kinds of this apparatus have, I believe, been brought out in the United States. An account of one, devised by himself, is given by Professor W. Harkness, in the Appendix to the *Washington Observations*, 1870. The principle of it is, that a series of five artificial stars attached to a chronograph cylinder is made to transit a single wire in a fixed telescope, at an apparent angular velocity corresponding with that of an equatoreal star crossing the wires of the transit instrument in the meridian, and at cor-

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responding intervals of time. The observer records chronographically the transit of each star over the wire, and the difference between his record of any transit and the previously-made mark on the chronograph sheet which corresponds with actual bisection of the star gives a measure of his absolute personal equation. Another kind of the same instrument was mentioned by Commander Green. I have not seen a written account of it, but I gather from his description that, in this case, a system of wires is made to move past a single star, instead of a set of stars past a single wire. As each wire passes, not exactly the star, but a point at a certain small known interval from it, it makes an automatic register on the chronograph. The observer also registers the transit on the same chronograph; and a comparison between the two registers, making due allowance for the small interval abovenamed (which is contrived purposely that there may be no confusion), gives a measure of the personal equation. The size of the artificial star can be varied to represent stars of different magnitudes.

The two kinds of personal equations in time signalling are found in combination, I believe thus: Two break-circuit chronometers, C_1 and C_2, are both made to register their beats on the same chronograph cylinder, for some little time, so as to give an absolute comparison between them, and the rate of gain of one upon the other. The observers now proceed to compare C_1 and C_2 in a similar manner to that described for time signalling. B goes to C_1 and sends signals by ear, which T receives by the Thomson's galvanometer and registers on the chronograph, which remains connected with C_2. The difference between the comparison of C_1 and C_2 thus obtained, and their absolute comparison (allowing for rate), may evidently be taken as the sum of B's personal equation in sending, and T's in receiving. B and T now change places, and repeat the above operations, in order to find the sum of T's personal equation in sending and B's in receiving. This is all that is needed, as the double operation gives the corrections to be applied in the case of either observer sending while the other receives.

In determinations of latitude with the transit instrument used as a zenith-telescope, from 6 to 12 pairs of stars observed on the meridian on three nights, making from 18 to 36 determinations in all, are considered to give a result sufficiently good, probably within about $0''\cdot5$ of the truth.

From the account I have here given of Commander Green's operations in these seas, it will, I think, be seen that they are simple and thoroughly practical, and executed with an accuracy which leaves nothing to be desired, being in fact surrounded with all the precautions and safeguards which should be looked for in work of a precise order. I believe that this is the first naval expedition as yet made for establishing secondary meridians by telegraphic time comparisons, and for exact determinations of latitude. The region which has been chosen is in every respect

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well suited for a first experiment, the facilities being great and the field large, while many uncertainties in the longitudes, especially on the south shore of the Caribbean Sea, where they amount to some five or six miles, need to be cleared up. In other parts of the world, however, the uncertainties are a good deal greater. It is not too much to hope that other nations will promptly follow the lead taken by the American hydrographers, and that especially our own Hydrographic Department will add this branch of work to the admirable maritime surveys in which it is justly pre-eminent. The vast and constantly spreading network of telegraphic cables and land lines will afford work for many years to come; and each extension of measurements of the class I have described will add accuracy to geographical knowledge and marine cartography.

Barbados, West Indies,
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On the Relative Power of Achromatic and Reflecting Telescopes.

By T. R. Robinson, D.D., F.R.S., &c.

In an article which appeared in *Les Mondes*, Jan. 20, 1876, by M. Radau, on large Telescopes, he remarks, after noticing the comparison of the relative illuminating power of Achromatics and Reflectors, which I made in the description of the Great Melbourne Telescope (*Phil. Trans.* 1869), "the theoretic proportion established by Mr. Robinson between equivalent apertures of a Reflector and Refractor is not however conformable to experience, which is entirely in favour of the Refractor."

Even were it true that an Achromatic shows objects better than an equivalent Reflector, it would not contradict my theory, which merely refers to light. The theory is, in brief, that a speculum collects in its focus a quantity of light proportional to its area, and a constant depending on the reflective power of its material; the Achromatic a quantity depending on its area, and a co-efficient which contains a negative exponential function of the aperture, and of course decreases more rapidly than the area increases. Therefore, though for small apertures the light of the Achromatic exceeds that of an equal speculum, yet as the aperture increases, the disparity decreases until at a size determined by the reflective power of the speculum and the refractive indices and absorptive power of the glasses, their lights become equal; and above that the Reflector predominates. Since, therefore, both the difficulty and cost of construction increase far more rapidly with aperture in the Achromatic than in the Reflector, it is evident that as far as light is concerned, the ultimate practical limit of telescopic research can only be obtained by the latter.

Having premised so much, I proceed to consider (1) what